Linear Regulator Series (3-terminal Regulator, LDO)

Problem Situations: Power Supply Does Not Start

Although linear regulators can be used to easily configure power supplies, the linear regulators may cause startup problems depending on the type of loads. This application note introduces cases where the power supplies do not start correctly in the linear regulators.

Frequent cases are introduced for problems where the output of a linear regulator does not start normally.

Case 1. Damage to devices and peripheral parts caused by hand soldering
Case 2. Startup problem caused by constant current load
Case 3. Startup problem caused by through current 1
Case 4. Startup problem caused by through current 2
Case 5. One side does not start in positive-negative power supply
Case 6. Startup problem caused by motor load

Case 1. Damage to devices and peripheral parts caused by hand soldering

Devices and peripheral parts are mounted on a PCB with soldering. In mass production, automated machines control the temperature and time for soldering to prevent problems. However, hand soldering using a soldering iron during a trial, rework, and so on, may cause problems where a power supply fails to start because of damage to the devices or the peripheral parts.

The conditions for mounting the devices are described in the "Mounting conditions" section of "Package information". The recommended conditions are described for the packages that can be mounted using a soldering iron. Perform the soldering according to the recommended conditions (Figure 1). However, if these conditions are exceeded, the devices may suffer damage, such as mold cracking and disconnection of bonding wires. If it is unavoidable to use a soldering iron during a trial and the like with the packages for which mounting with soldering is not recommended, perform the soldering in a short time. In this case, there is a strong possibility that the devices may be damaged if the power supply does not start normally.

Recommended conditions for mounting the TO252-3 package using a soldering iron

Soldering iron temperature:	380°C or less
Mounting time:	4 s or less

Figure 1. Example of the recommended conditions for mounting the TO252-3 package using a soldering iron

The recommended conditions are also described for surface mount parts, such as resistors and ceramic capacitors. Perform the soldering according to the recommended conditions (Figure 2). However, the possibility increases that the parts may be damaged during the mounting using a soldering iron as the size of parts decreases. The parts with the 1005 (0402) size or smaller are especially susceptible to an external stress. The terminal electrodes may be separated due to overheating, an external force from the iron tip, or reuse of the same parts, causing an open failure. It is difficult to visually detect whether the terminal electrode is separated. If the power supply cannot output the prescribed voltage, or if an abnormal waveform appears, there is a strong possibility that the peripheral parts may be damaged.

Recommended conditions of hand soldering for resistors

Except 0603 (0201) and 0602 (01005) sizes

Iron tip temperature:	350°C
Soldering time:	4 s Max.
Frequency:	1
Wattage:	20 W Max.

Figure 2. Example of recommended conditions of hand soldering for resistors

Case 2. Startup problem caused by constant current load

In a linear regulator equipped with an over current protection circuit that has the fold back characteristic (resembling the shape of a numeral "7"), the output voltage may not rise if a constant current load is drawn before the regulator starts up.

First, we explain the startup sequence in the case of a normal load (resistive load). Figure 3 shows an example of the fold back ("7") characteristic of the over current protection circuit. Figure 4 shows the startup waveforms of a circuit with the regulator output being connected to a capacitor of 100 µF and a resistive load in which a load current of 500 mA flows at 5 V.

The output voltage and current are both zero at point (A) immediately before the IC starts up, and the fold back ("7") curve starts from the lower left. The IC starts up when V_{CC} is supplied. Then, an inrush current flows to charge the output capacitor of the regulator. The inrush current activates the over current protection circuit of the IC and the current is regulated to approximately 300 mA.

Then, the output voltage increases and the operating point moves to (B). This accompanies the increase in the inrush current along the fold back ("7") curve. The output voltage and the inrush current further increase along the fold back ("7") curve, and the operating point moves to (C) and (D). At point (D), the current limit value during the normal operation is reached. When the output voltage approaches the specified value, the charging current to the output capacitor decreases to point (E), the steady operation point.

In this way, if the over current protection circuit of the linear regulator has the fold back ("7") characteristic, the startup characteristics of the linear regulator shows the transition from the zero point along the fold back ("7") curve. If the load is a resistor or capacitor, the output voltage rises without fail as long as the current is supplied to the output, although the current limit may be applied during startup.

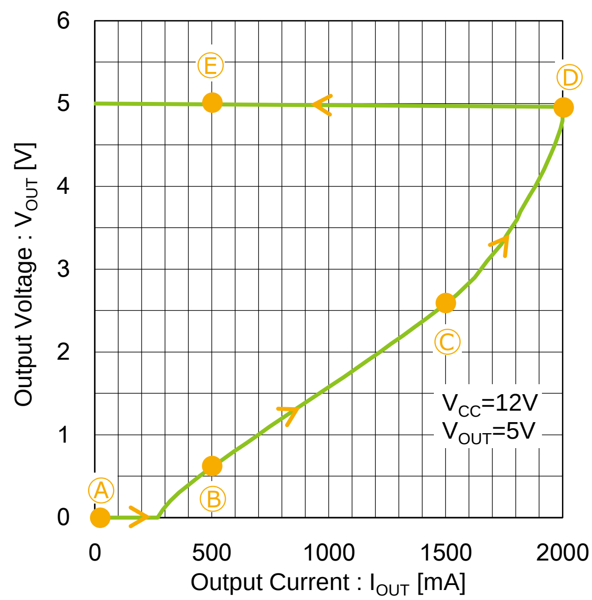

Figure 3. Example of the fold back characteristic of the over current protection circuit and the transition of the operating point when the load is resistive

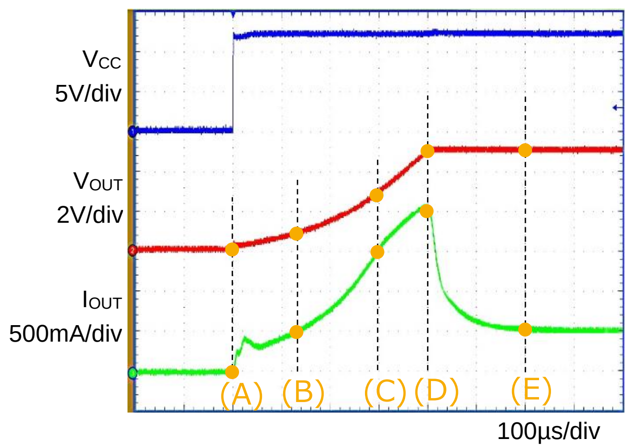

Figure 4. Example of the startup waveforms
V_{CC}=12V, V_{OUT}=5V, C_{OUT}=100µF, I_{OUT}=500mA

Next, we consider the case of a constant current load. If a constant current load is drawn before the IC starts up, a current flows in the diode between the IC output pin and the ground and a forward voltage is generated. As a result, the voltage of the output pin becomes -1 V_F (approximately -0.7 V). This diode can be an electrostatic breakdown protection diode or parasitic diode (Figure 5).

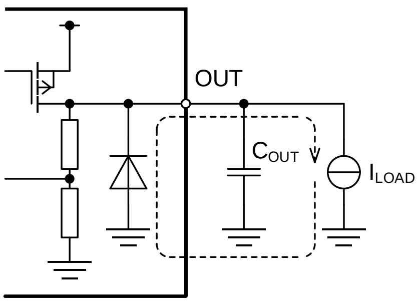

Figure 5. Forward voltage is generated by a constant current and the voltage of the output pin becomes -1 V_F

For example, with a constant current load of 500 mA, the operating point before the IC starts up is located at point (A) in Figure 6. Although the supply of the output current starts when the IC starts up, the supply current at the output voltage of -0.7 V is further decreased from the current at 0 V, decreasing to 200 mA in this example. The output voltage cannot rise because the supply current is only 200 mA against the load current of 500 mA. As a result, the output voltage cannot rise and a steady operating point is formed at (B), leading to a startup problem.

Next, we consider the case of connecting a constant current load after the IC has started. The regulator operates without problem if a constant current load is connected while the specified voltage is obtained at the IC output. This is because the current has a sufficient supply capacity at the specified voltage. If the output is short circuited in this situation, the operating point moves to point (A) in Figure 6 and a startup problem occurs as described above.

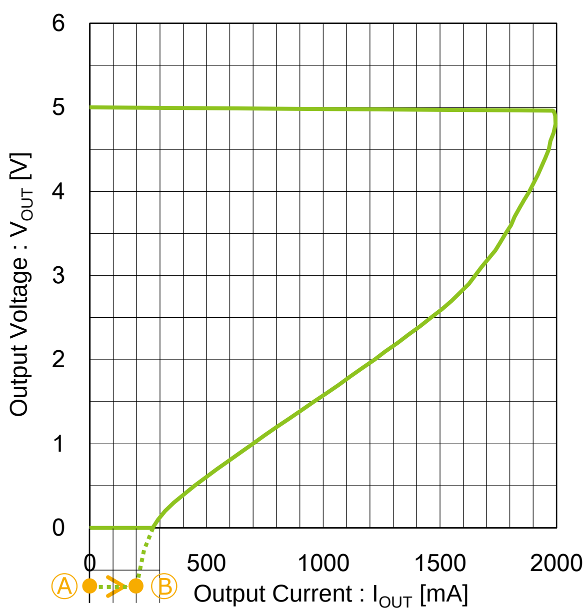

Figure 6. Transition of the operating point during startup when the load is a constant current

For troubleshooting, it is necessary to select a product in which the current value that can be supplied from the IC during startup is larger than the value of the constant current load. In a linear regulator equipped with an over current protection circuit that has the fold back (“7”) characteristic, the current value that can be supplied at the output of 0 V is set to a small value compared with the peak current because of the shape of the characteristic. It is also often the case that this current value is not guaranteed. For the usage with a constant current load, we recommend using a linear regulator whose over current protection circuit has the drooping type characteristic. The startup can be secured with the drooping type characteristic, because the current value that can be supplied at the output of 0 V is close to the peak current as shown in Figure 7.

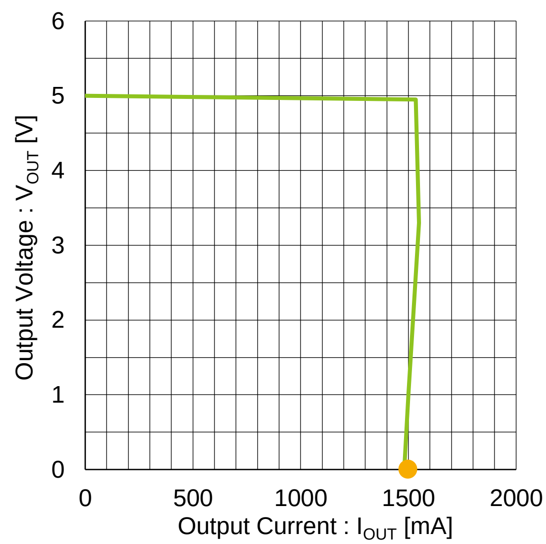

Figure 7. Example of the drooping type characteristic of the over current protection circuit

In addition, the elements may be degraded or destroyed if a current flows in the electrostatic breakdown protection diode or the parasitic diode between the IC output pin and the ground. To prevent this, connect a Schottky barrier diode in parallel to the output pin (Figure 8).

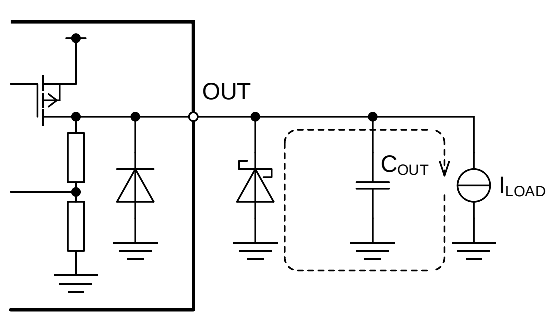

Figure 8. Terminal protection against reverse voltage

Case 3. Startup problem caused by through current 1

Figure 9 shows the circuit current characteristic of a circuit block connected with the output of a linear regulator. Although this circuit is designed to operate when the power supply voltage of 1.8 V or greater is supplied, a large current flows near 0.7 V before the circuit operates stably. This is a condition in which a node in the circuit becomes unstable and the through current flows between the power supply and the ground. This is caused by a lack of attention to the circuit operation below the operating power supply voltage.

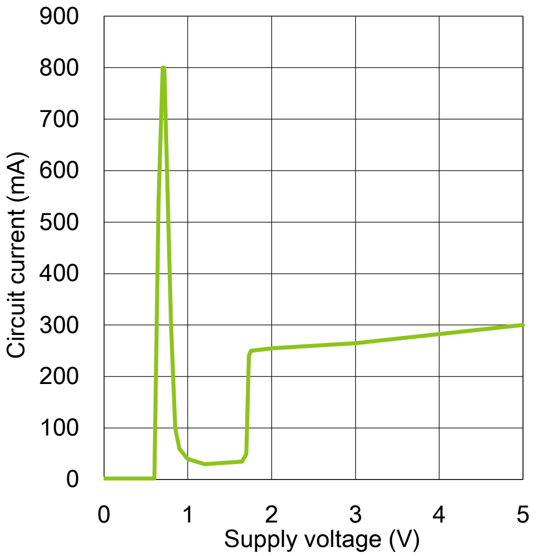

Figure 9. Circuit current characteristic of a circuit block

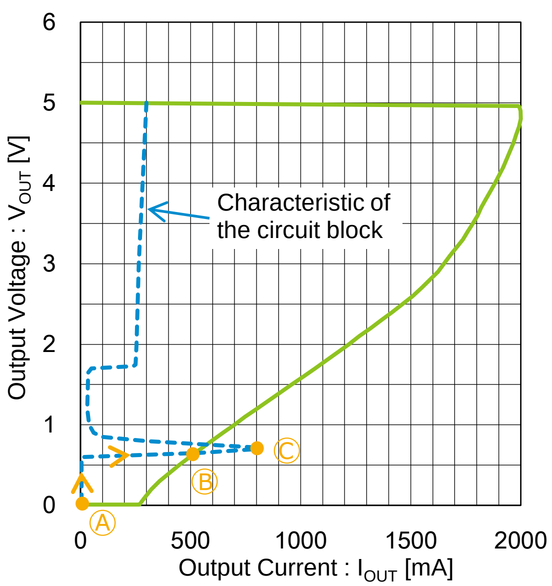

Figure 10. Transition of the operating point when the circuit block with the through current is started

If this circuit is connected with a linear regulator with the over current protection circuit described in Figure 3 above, the operating point during startup transits as shown in Figure 10. The operating point begins to start up from point (A) and is supposed to move to point (C), at which the through current flows. However, the current limit is applied at point (B) by the over current protection circuit. Since a steady point is formed here, the output voltage cannot rise and a startup problem occurs.

In actual cases, the startup is often accomplished normally due to the noise during startup or the parasitic elements. A design error may not be noticed until a problem occurs in mass production. To prevent such a problem, measure the current characteristics of the circuit block to be connected with the linear regulator, and confirm that there is no excessive peak current.

Case 4. Startup problem caused by through current 2

Although this is similar to Case 3, the circuit current of the circuit block differs between the rising and falling periods of the power supply in this case. Figure 11 shows an example of the circuit current.

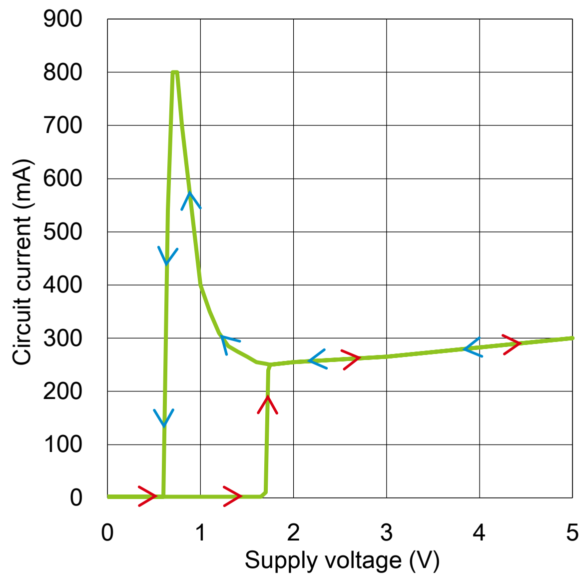

Figure 11. Circuit current characteristic with different current values between the rising and falling periods

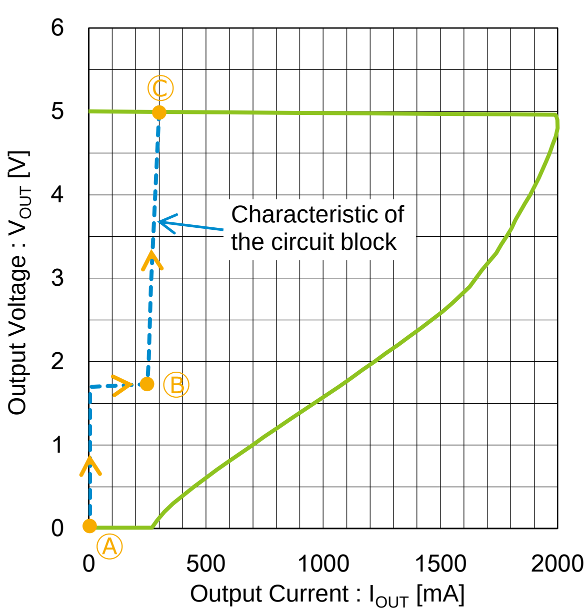

Figure 12. Transition of the operating point when the circuit block in Figure 11 is started

If this circuit block is connected with a linear regulator with the over current protection circuit described in Figure 3 above, the operating point during startup transits as shown in Figure 12. The operating point starts operating from point (A) and moves to points (B) and (C), and the startup is accomplished normally. If you only look at this, it appears as if there is no problem.

Next, we consider the case where an inrush current flows to charge the output capacitors during startup. Figures 13 and 14 show the assumed block diagram of the power supply and the startup waveforms, respectively. When input V_{IN} of the linear regulator rises, output V_{OUT} also rises following the input. When V_{OUT} reaches 1.8 V, the circuit block starts operating and the inrush current flows to the multiple capacitors connected with V_{OUT} [point (a)]. Output current I_O of the linear regulator increases and the over current protection circuit is activated, causing the output voltage to temporarily drop to 0.6 V [point (b)]. Since I_O decreases when the charging of the capacitors is finished, the output voltage starts rising again and finally reaches the specified value [point (c)]. The startup is accomplished normally if the circuit current in the circuit block does not increase during the falling period of the power supply, unlike in Figure 11.

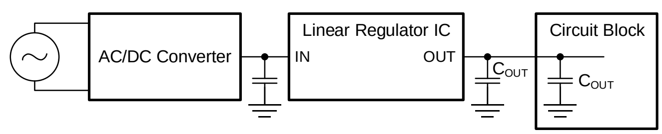

Figure 13. Configuration diagram of the power supply

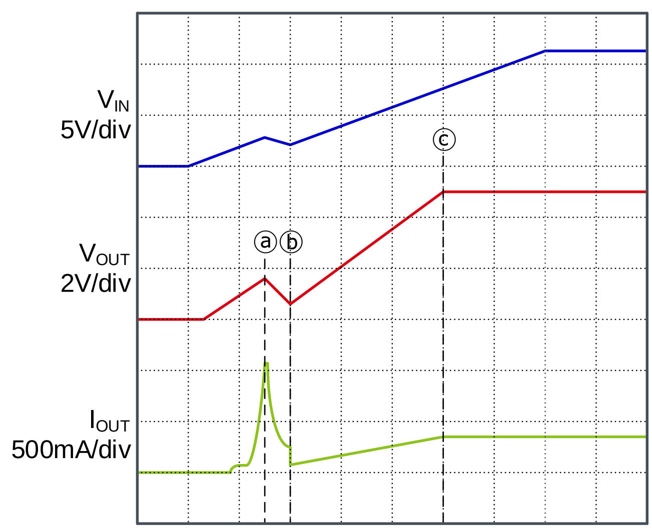

Figure 14. Startup waveforms when the circuit current does not increase during the falling period of the power supply

Next, we consider the transition of the operating point if the circuit current increases during the falling period of the power supply. Figure 15 shows a graph of the operating point during startup in Figure 14 superimposed on the characteristic of the over current protection. The operating point starts operating from point (A). When V_{OUT} reaches 1.8 V, the circuit block starts operating and the inrush current to the capacitors increases the current. The over current protection circuit is activated at point (B). The protection circuit causes the output to fold back to point (C). Although the circuit block requires a current of 800 mA [point (D)] at the voltage of point (C) as shown in Figure 11, the protection circuit regulates the current to 500 mA. Therefore, a steady point is formed here and the output voltage is not allowed to increase, causing a startup problem. As a result, the waveforms in Figure 14 are fixed with the output voltage of 0.6V [point (C) in Figure 15] as shown in Figure 16.

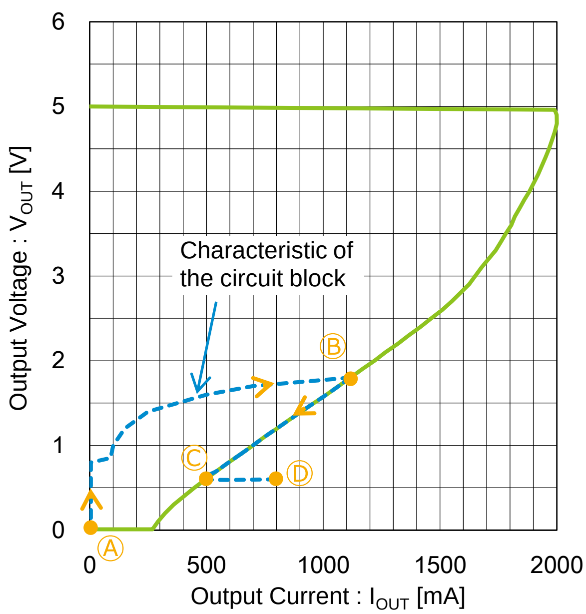

Figure 15. Transition of the operating point when the circuit current increases during the falling period of the power supply

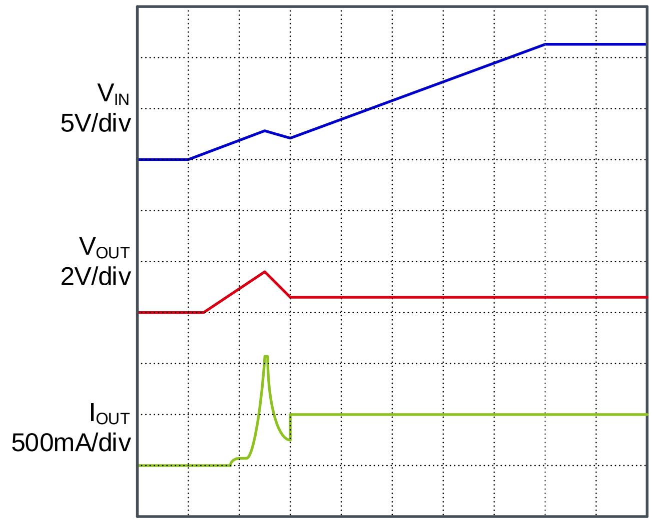

Figure 16. Waveforms when a startup problem has occurred

As explained above, when the circuit current characteristic of the circuit block to be connected with the output of a linear regulator shows a non-monotonic increase with the power supply voltage or significantly different currents between the rising and falling periods of the power supply, it is necessary to understand that there is a hidden possibility that a problem may occur when the balance is lost between the characteristics of the over current protection circuit and the value of the inrush current, even if the operation is normal during a trial.

Case 5. One side does not start in positive-negative power supply

For a positive-negative power supply as shown in Figure 17, the rising speed of the power supply is different between the positive and negative sides. For this reason, when there is a load such as R_{L3} or an unintended current path formed by multiple circuits between the positive and negative sides, the one side that rose first draws a current from the output of the other through R_{L3} (through the path described by the broken line), and a reverse voltage is applied to the output of the positive voltage regulator. Therefore, a startup problem occurs as in Case 2.

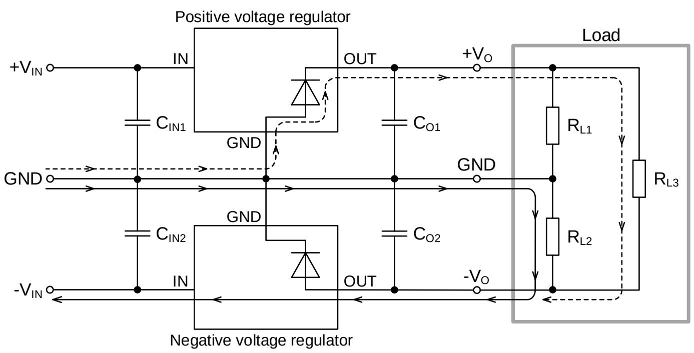

Figure 17. Current path when the negative power supply started up first

The following countermeasures can be considered:

1. Shut off the R_{L3} path.
2. Connect a Schottky diode with a low V_F between the output and GND to decrease the value of the reverse voltage and reduce the failure of the output voltage to rise (Figure 18). It is necessary to select a product in which the current value that can be supplied from the IC during startup is larger than the value of the reverse current. However, there is no 100% guarantee of the normal rising due to variation and the like.
3. Use linear regulators whose over current protection circuit has the drooping type characteristic. In addition, the elements may be degraded or destroyed if a current flows in the electrostatic breakdown protection diode or the parasitic diode between the IC output pin and the ground. To prevent this, connect a Schottky barrier diode in parallel to the output pin (Figure 18).

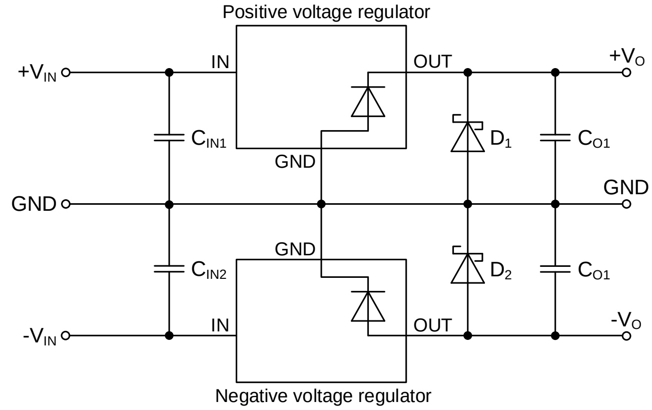

Figure 18. Diode for protecting the output terminal

Case 6. Startup problem caused by motor load

The startup current that flows when a motor starts rotating is several times larger than the current at the rated rotation. Figure 19 shows a graph of the characteristic during the motor startup superimposed on the fold back characteristic of the over current protection circuit installed on the linear regulator. The operating point of this motor starts from point (A). The startup current increases with the voltage rise, and then the operating point moves through points (B) and (C) to point (D), which is the operating point at the rated rotation. In this example, a steady point is formed at point (B), where the startup current of the motor (broken blue line) exceeds the current for the over current protection (solid green line). Therefore, the output voltage cannot rise over 0.35 V, causing a startup problem.

In actual cases, the startup can be often accomplished with this degree of current difference. However, point (C), which is the peak value of the current during startup, further shifts to the right side in the graph when the motor is loaded, increasing the possibility of the startup failure.

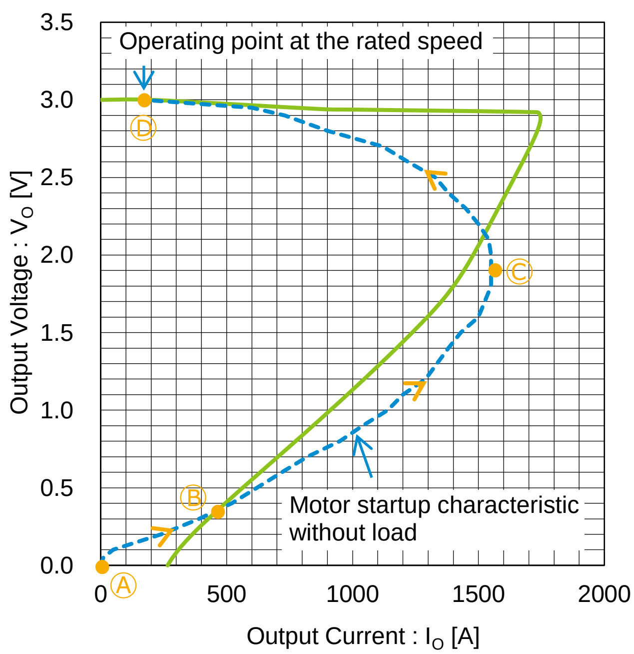

Figure 19. Example of the transition of the operating point during the motor startup

For countermeasures, use a linear regulator equipped with the over current protection circuit that has the drooping type characteristic capable of outputting a current larger than the value of the motor startup current, or use a motor driver IC.

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